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Abgasreinigung

Purification de gaz d'échappement

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(56) References cited:
EP-A- 0 366 876
EP-A- 0 443 625
WO-A-91/03315
DE-A- 3 708 508
DE-A- 4 028 720

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EP 0 608 619 B1

Description

The present invention relates to the purification of gases and in particular to the reduction of the emission of particulate and other materials from the exhausts of internal combustion engines.

One of the major problems associated with the development and use of internal combustion engines is the noxious exhaust emissions from such engines. Two of the most deleterious materials, particularly in the case of diesel engines, are particulate carbon and oxides of nitrogen (NO_x). Increasingly severe emission control regulations are forcing internal combustion engine and vehicle manufacturers to find more efficient ways of removing these materials in particular from internal combustion engine exhaust emissions. Unfortunately, in practice, it is found that techniques which improve the situation in relation to one of the above components of internal combustion engine exhaust emissions tend to worsen the situation in relation to the other. Even so, a variety of systems for trapping particulate emissions from internal combustion engine exhausts have been investigated, particularly in relation to making such particulate emission traps capable of being regenerated when they have become saturated with particulate material.

Examples of such diesel exhaust particulate filters are to be found in European Patent Application EP 0 010 384; US Patents 4,505,107; 4,485,622; 4,427,418; and 4,276,066; EP 0 244 061; EP 0 112 634 and EP 0 132 166.

In all the above cases, the particulate matter is removed from diesel exhaust gases by a simple, physical trapping of particulate matter in the interstices of a porous, usually ceramic, filter body, which is then regenerated by heating the filter body to a temperature at which the trapped diesel exhaust particulates are burnt off. In most cases the filter body is monolithic, although EP 0 010 384 does mention the use of ceramic beads, wire meshes or metal screens as well. US Patent 4,427,418 discloses the use of ceramic coated wire or ceramic fibres.

In a broader context, the precipitation of charged particulate matter by electrostatic forces also is known. However, in this case, precipitation usually takes place upon large planar electrodes or metal screens.

Also, PCT specification WO 91/03315 discloses an air purifier consisting of two cylindrical co-axial electrodes the space between which is filled with beads of a dielectric material. In use a plasma is generated in the region containing the dielectric beads, and it is this plasma which carries out the purification process. The beads of dielectric material in general merely enable stable plasma conditions to be maintained and control the aerodynamic resistance of the purifier, although if desired the beads can be adapted to catalyse purification reactions. Although the pellets are described as being dielectric, their dielectric constant is only about that of air. EP specification 0 443 625 A1 discloses an internal combustion engine exhaust purifier which includes a filter element in the form of a honeycomb made of a composite ceramic material the dielectric constant of which varies both axially and radially. In use the purifier acts as a simple filter for particulates (soot) in the exhaust gases from an internal combustion engine, but when the filter is blocked, then the element is subjected to microwave radiation to heat it to burn off the soot. The idea of varying the dielectric constant is to cause the filter element to be heated most where the deposits of soot are thickest.

According to the present invention there is provided a gas purification device, comprising a reactor chamber adapted to form part of a gas flow system, wherein the reactor chamber includes an active element through which in use gases to be purified are constrained to pass, consisting of a gas permeable body of pellets of a material having a high dielectric constant and at least one pair of electrodes by means of which the pellets within the active element can be charged electrically.

According to the invention in one aspect there is provided a reactor for reducing exhaust emissions from internal combustion engines, comprising a reactor chamber adapted to form part of an internal combustion engine exhaust system, the reactor chamber including an active element through which, in use, exhaust gases are constrained to pass consisting of a gas permeable body of pellets of a heat resistant material having a high dielectric constant and at least one pair of electrodes by means of which the pellets within the active element can be charged electrically.

According to the invention in a second aspect there is provided an exhaust system for an internal combustion engine, including a reactor chamber including an active element through which in use exhaust gases are constrained to pass consisting of a gas permeable body of pellets of a heat resistant material having a dielectric constant of at least approximately one thousand and at least one pair of electrodes by means of which the pellets within the active element can be charged electrically.

Preferably there is included more than one reactor chamber and there is provided means whereby exhaust gases can be diverted from one reactor chamber to another.

Preferably the electrodes are in the form of metal grids which serve also to retain the pellets in position within the active element.

The pellets can be regular or irregular in shape and, preferably, in addition to having a high dielectric constant, the material out of which they are made has ferroelectric properties. Suitable materials are lead magnesium niobate, lead titanate, lead zirconate or barium titanate.

Preferably there may be provided also a second set of electrodes so positioned that in use exhaust gases pass the additional electrodes prior to entering a reactor chamber thereby enabling an electric charge to be created on particulate matter contained in the exhaust gas

prior to its passage through the active element in the reactor chamber.

According to the invention in another aspect there is provided a method of reducing exhaust emissions from internal combustion engines, comprising the operations of passing exhaust gases from an internal combustion engine through a reactor chamber including an active element consisting of a gas permeable body of pellets of a heat resistant material having a dielectric constant of at least approximately one thousand and applying an electric potential to the pellets in the active element.

Preferably the pellets are heated to a temperature sufficient to burn off carbonaceous deposits upon them; a suitable way of doing this continuously is to apply an AC potential of the order of tens of kilovolts to the pellets; the resulting microplasmas generated in the spaces between the pellets makes them self-cleaning.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which

Figure 1 is a longitudinal section of a portion of an experimental reactor for reducing exhaust emissions from an internal combustion engine.

Figure 2 is a longitudinal section of a rapid flow reactor chamber embodying the invention for use in removing particulate and other emissions from the exhaust gases emitted by a diesel engine.

Figure 3 is a representation of another embodiment of the invention,

Figure 4 shows particulate deposits on a filter paper included in a test system downstream of an experimental exhaust gas purification device according to Figure 1 of the drawings at various intervals from the start of an experimental run both with the invention in operation and with the invention inoperative, and

Figure 5 shows part of two infra red absorption spectra of a test gas passed through the exhaust gas purification device of Figure 1, both with it operative and inoperative.

Referring to Figure 1 of the drawings, an experimental internal combustion engine exhaust purification apparatus consists of a reactor chamber 101, only one end of which is shown and described as the other end is identical. Each end of the reactor chamber 101 consists of a metal end-piece 102 which is adapted to fit inside a cylindrical envelope 103 which is made of an insulating ceramic material. A gas-tight seal between the end-piece 102 and the envelope 103 is made by an O-ring seal 104 which seats in a groove 105 formed in the end-piece 102. The end-piece 102 consists of an inner section 106 and an outer section 107 which are held together by a ring of set screws 108. A double mesh 109 made of stainless steel is held between the inner and outer sections 106 and 107 of the end-piece 102. The mesh 109 holds in place a body of ferro-electric pellets 110 and also acts as an electrode by means of which a voltage of the order of 20 kilovolts can be applied to the pellets 110 via a connection 111 to one of the set screws 108. The outer section 105 of the end-piece 102 has a hollow axial stub 112 by means of which exhaust gas from an internal combustion engine, not shown, can be admitted to the reactor chamber 101. A similar stub on the corresponding end-piece (not shown) at the other end of the reactor chamber 101 enables the purified exhaust gas to leave the reactor chamber 101. The reactor chamber 101 needs to be isolated electrically from the remainder of the exhaust system of which it forms a part. This can be done in any convenient way. For example, insulating coupling sleeves can be used which fit over the stub 112 and its counterpart at the other end of the reactor chamber 101. Alternatively the stubs can be isolated electrically from the remainder of their respective end pieces.

Referring to Figure 2 of the drawings, a reactor chamber 201 for use with a diesel engine exhaust system to reduce the emission of particulate carbonaceous material therefrom consists of a generally cylindrical outer portion 202, an inner portion 203 and an end plate 204 which is attached by means of a ring of bolts 205 to a flange 206 which forms part of the outer portion 202. A gas-tight seal between the outer portion 202 of the reactor chamber 201 and the end plate 204 is made by means of a gasket 207. The inner portion 203 of the reactor chamber 201 and the end plate 204 are adapted to receive and hold a body 208 of ferro-electric pellets 209 which are packed between two metal mesh cylinders 210 and 211. The cylinders 210 and 211 act as electrodes by means of which the pellets 209 can be charged. Also included is a cylindrical electrode 212 which surrounds the body 208 of pellets 209. The electrode (optional) 212 enables particulate carbonaceous material (soot) in exhaust gases 213 from a diesel engine (not shown) to be charged prior to their passage into and through the body 208 of pellets 209. An inlet port 214 and bleed valve 215 enable an oxidising gas to be fed from a reservoir 216 into the reactor chamber 201, if desired, to assist in regenerating the body 208 of pellets 209 by burning off the soot deposited upon them. Alternatively, a reducing gas such as ammonia or urea can be admitted into the reactor chamber 201 to reduce NO_x to N_2.

In use, a high DC voltage of some kilovolts is applied to the outer electrode 210, which causes the pellets 209 to become strongly polarised and act as an electrostatic filter. The action of the body 208 of pellets 209 is enhanced by applying a similar voltage to the electrode 212 so as to charge soot particles in the exhaust gases 213.

If the body 208 of pellets 209 have become saturated with soot particles, it can be regenerated in situ by

a number of techniques. For example, an AC or pulsed DC voltage can be applied to the body 208 of pellets 209 by means of the electrodes 210 and 211 so as to create microplasmas on the surfaces of the pellets 209 which oxidise the soot particles. Alternatively, resistive heating of the pellets 209 can be employed using internal heating elements. Another possibility is to use microwave or RF radiation to create the microplasmas. In all cases, the regeneration can be aided by bleeding oxygen into the reactor chamber 201 via the port 214 and bleed valve 215. Yet another possible way of regenerating the pellets 209 is to increase the temperature of the exhaust gases by making the engine run hot for a short period.

Figure 3 illustrates an arrangement which uses two reactor chambers 301 and 302, which are not illustrated in detail. Each of the reactor chambers 301 and 302 consists of a cylindrical inlet 303, a conical body portion 304 and an outlet 305. Also there are a perforated grid 306, a body 307 of ferro-electric pellets 308, a second perforated grid 309, which together with the grid 306 holds the pellets 308 in place, and an auxiliary charging electrode (not shown). The grid 309 is earthed and the grid 306 is insulated, so as to be capable of acting as a high voltage charging electrode.

The reactor chambers 301 and 302 are arranged in a Y-configuration and at their junction is placed a flap gate valve 310. In use, the flap valve 310 is arranged to close off one of the reactor chambers 301 and 302 so that it can be regenerated after use and then be ready for use while the other reactor chamber is in use, and vice versa. In order to assist starting of an engine in the exhaust system of which the reactor chambers 301, 302 are included, the flap valve 310 can be positioned so that both reactor chambers 301, 302 are in circuit together.

Referring to Figure 4, there is shown two groups of filter papers which were installed in an experimental rig downstream of the exhaust gas purifier described with reference to Figure 1, through which smoke was passed. It can be seen that when a potential difference of about 20 kV was applied across the body of ferroelectric pellets 109 even after a period of twelve minutes, substantially all the particulate matter in the smoke was removed by the gas purifier, whereas when no potential difference existed across the body of ferroelectric pellets 109, the filter was totally blocked by particulate matter in the smoke.

Figure 5 shows the results of a similar experiment in which toluene was present in a test gas passed through a purifier as described with reference to Figure 1. As can be seen, the majority of the toluene was removed from the test gas.

It has been found in practice that if the applied potential is AC rather than DC then the ferro-electric pellets show a degree of self-cleaning ability and the lifetime before regeneration by heating is necessary is increased considerably. Under the normal range of diesel engine operating conditions the pellets are completely self cleaning when operated in the AC mode.

The self-cleaning effect is enhanced if the pellets are irregular in shape because the corners enhance the formation of microplasmas which assist the oxidation of carbonaceous deposits. Such microplasmas also assist the reduction of nitrous oxides when a reducing gas is added to the exhaust gases in the reactor chamber.

The dielectric constant of most ceramic/ferro-electric materials is a function of temperature with a well-defined maximum value. The material for the pellets 110, 209 therefore can be chosen in accordance with the position in the exhaust system at which the reactor is to be placed. For example, if it is to be placed at the exhaust manifold end of the exhaust system where the operating temperature is likely to be about 5 - 600°C, then materials such as lead niobate, with or without magnesium as a constituent of the material, or lead titanate are suitable, whereas if the reactor is to be placed at the tail pipe end of the exhaust system where operating temperatures are about 300°C, then lead zirconate or related compounds are suitable. Other materials can be chosen for use in intermediate positions.

A particularly useful material is barium titanate because it appears to have catalytic properties which promote the reduction of NO_x to N_2 as well as the oxidation of carbonaceous particles (soot) to $CO/CO_2/H_2O$.

Claims

1. A device for removing particulate pollutants from a gaseous medium, comprising a reactor chamber (201) adapted to form part of a gas flow system containing a body (208) of pellets (209), means (202, 203, 204) for constraining a gaseous medium from which particulate pollutants are to be removed to pass through the body (208) of pellets (209), wherein the pellets (209) are made of a material having a high dielectric constant and there is provided means (210, 211) by means of which the pellets (209) can be charged electrically.

2. A device according to Claim 1 wherein the means by means of which the pellets (209) can be charged comprises a pair of gas permeable electrodes (210, 211) forming part of a containment for the pellets (209).

3. A device according to Claim 1 or Claim 2 wherein the material from which the pellets (209) are made has ferro electric properties.

4. A device according to Claim 3 wherein the pellets (209) are made from lead magnesium niobate, lead titanate, lead zirconate or barium titanate.

5. A device according to any of Claims 1 to 4 wherein there is included an electrode, or electrodes (212) so positioned that, in use, the gaseous medium passes them before entering the body (208) of pel-

lets (209).

6. A device according to any of Claims 1 to 5 wherein there is included means (214, 215, 216) for adding a reactive gas to the gaseous medium.

7. A device according to any of Claims 1 to 6 adapted to form part of an internal combustion engine exhaust system.

8. A device according to Claim 7 wherein the material from which the pellets (209) are made is adapted to catalyse the reduction of No_x to N_2.

9. A device according to Claim 7 or Claim 8 wherein the material from which the pellets (209) are made is adapted to catalyse the conversion of carbonaceous material to a gaseous mixture of carbon monoxide, carbon dioxide and water.

10. A device according to Claim 8 or Claim 9 wherein the pellets (209) are made of barium titanate.

11. A method of reducing exhaust gas emissions from an internal combustion engine comprising the steps of passing exhaust gases from an internal combustion engine through a body (208) of pellets made from a heat resistant material having a high dielectric constant and applying an electric potential to the pellets (208) sufficient to cause particulate matter contained in the exhaust gases to be deposited upon the pellets (208).

12. A method according to Claim 11 wherein there is included the operation of adding to the exhaust gases a reactive gas adapted to react with pollutants contained in the exhaust gases.

13. A method according to Claim 12 wherein the reactive gas is adapted to reduce gaseous nitrogenous oxides contained in the exhaust gases.

14. A method according to Claim 13 wherein the reactive gas is ammonia or urea.

15. A method according to any of Claims 11 to 14 wherein there is included the operation of subjecting the exhaust gases to an electric field prior to their passage through the body of pellets (209) so as to charge electrically particulate matter entrained in the exhaust gases prior to their passage through the body of pellets (209).

16. A method according to any of Claims 11 to 15 wherein the electric potential is unidirectional.

17. A method according to Claim 16 wherein the unidirectional potential is pulsed.

18. A method according to any of Claims 11 to 17 wherein the electric potential is of the order of 20 kilovolts.

Patentansprüche

1. Vorrichtung zum Entfernen bzw. Abscheiden von aus Partikeln bestehenden bzw. partikelförmigen Schmutz- bzw. Schadstoffen von einem gasförmigen Medium, welche eine Reaktions- bzw. Reaktorkammer (201) umfaßt, die angepaßt ist, daß sie einen Teil eines Gasströmungssystems bildet, welches einen Körper (208) mit Pellets (209) und Mittel (202, 203, 204) enthält, um ein gasförmiges Medium, von dem die aus Partikeln bestehenden Schmutzstoffe entfernt werden sollen, dazu zu zwingen, durch den Körper (208) mit Pellets (209) hindurchzugelangen bzw. hindurchzuströmen, bei der die Pellets (209) aus einem Material hergestellt sind, das eine große Dielektrizitätskonstante aufweist, und Mittel (210, 211) vorgesehen sind, mit deren Hilfe die Pellets (209) elektrisch aufgeladen werden können.

2. Vorrichtung nach Anspruch 1, bei der das bzw. die Mittel, mit deren Hilfe die Pellets (209) aufgeladen werden können, ein Paar aus gasdurchlässigen bzw. durchströmbaren Elektroden (210, 211) umfaßt, das bzw. die einen Teil einer Einschließung bzw. eines Behälters für die Pellets (209) bildet.

3. Vorrichtung nach Anspruch 1 oder 2, bei der das Material, aus dem die Pellets (209) hergestellt sind, ferroelektrische Eigenschaften aufweist.

4. Vorrichtung nach Anspruch 3, bei der die Pellets (209) aus Bleimagnesiumniobat, Bleititanat, Bleizirkonat oder Bariumtitanat hergestellt sind.

5. Vorrichtung nach einem der Ansprüche 1 bis 4, bei der eine Elektrode oder Elektroden (212) so angeordnet ist bzw. sind, daß das gasförmige Medium diese in Gebrauch passiert, bevor es in den Körper (208) mit Pellets (209) gelangt.

6. Vorrichtung nach einem der Ansprüche 1 bis 5, bei der Mittel (214, 215, 216) zum Hinzufügen eines reaktiven Gases zu dem gasförmigen Medium enthalten sind.

7. Vorrichtung nach einem der Ansprüche 1 bis 6, die angepaßt ist, daß sie einen Teil eines Verbrennungsmotor-Abgassystems bildet.

8. Vorrichtung nach Anspruch 7, bei der das Material, aus dem die Pellets (209) hergestellt sind, angepaßt ist, daß es die Reduktion von NO_x zu N_2 katalysiert.

9. Vorrichtung nach Anspruch 7 oder 8, bei der das Material, aus dem die Pellets (209) hergestellt sind, angepaßt ist, daß es die Umwandlung von kohlenstoffhaltigem Stoff in ein gasförmiges Gemisch aus Kohlenmonoxid, Kohlendioxid und Wasser katalysiert.

10. Vorrichtung nach Anspruch 8 oder 9, bei der die Pellets (209) aus Bariumtitanat hergestellt sind.

11. Verfahren zur Reduzierung bzw. Minderung von Abgasemissionen von einem Verbrennungsmotor, das die Schritte umfaßt, das Abgase von einem Verbrennungsmotor durch einen Körper (208) mit Pellets hindurchgelangen bzw. hindurchströmen, die aus einem wärme- bzw. hitzeresistenten Material hergestellt sind, das eine große Dielektrizitätskonstante aufweist, und das ein elektrisches Potential an die Pellets (208) angelegt wird, das ausreicht um zu bewirken, daß sich der aus Partikeln bestehende Stoff, der in den Abgasen enthalten ist, auf den Pellets (208) abscheidet bzw. niederschlägt.

12. Verfahren nach Anspruch 11, bei dem der Vorgang eingeschlossen ist, daß den Abgasen ein reaktives Gas hinzugefügt wird, das angepaßt ist, daß es mit Schmutz- bzw. Schadstoffen reagiert, die in den Abgasen enthalten sind.

13. Verfahren nach Anspruch 12, bei dem das reaktive Gas angepaßt ist, daß es in den Abgasen enthaltene gasförmige, stickstoffhaltige Oxide reduziert.

14. Verfahren nach Anspruch 13, bei dem das reaktive Gas Ammoniak oder Harnstoff bzw. Carbamid ist.

15. Verfahren nach einem der Ansprüche 11 bis 14, bei dem der Vorgang eingeschlossen ist, daß die Abgase vor ihrer Passage durch den Körper mit Pellets (209) einem elektrischen Feld ausgesetzt werden, so daß der in den Abgasen mitgerissene, aus Partikeln bestehende Stoff vor seiner Passage durch den Körper mit Pellets (209) elektrisch aufgeladen wird.

16. Verfahren nach einem der Ansprüche 11 bis 15, bei dem das elektrische Potential unidirektional ist.

17. Verfahren nach Anspruch 16, bei dem das unidirektionale Potential gepulst ist.

18. Verfahren nach einem der Ansprüche 11 bis 17, bei dem das elektrische Potential von der Größenordnung von 20 Kilovolt ist.

Revendications

1. Dispositif pour enlever des polluants particulaires d'un milieu gazeux, ce dispositif comprenant une chambre de réaction (201) convenant bien pour faire partie d'un système ou circuit de circulation de gaz, contenant un corps (208) de pastilles ou granules (209), des moyens (202, 203, 204) pour obliger un milieu gazeux dont on doit enlever les polluants particulaires à traverser le corps (208) de pastilles ou granules (209), les pastilles ou granules (209) étant constitués d'une matière ayant une constante diélectrique élevée et le dispositif comportant des moyens (210, 211) permettant de charger électriquement les pastilles ou granules (209).

2. Dispositif selon la revendication 1, dans lequel le moyen permettant de charger les pastilles ou granules (209) comprend une paire d'électrodes (210, 211) perméables à du gaz et faisant partie d'un agencement de retenue des pastilles ou granules (209).

3. Dispositif selon la revendication 1 ou la revendication 2, dans lequel la matière dont les pastilles ou granules (209) sont constitués possède des propriétés ferroélectriques.

4. Dispositif selon la revendication 3, dans lequel les pastilles ou granules (209) sont en niobate de magnésium-plomb, en titanate de plomb, en zirconate de plomb ou en titanate de baryum.

5. Dispositif selon l'une quelconque des revendications 1 à 4, dans lequel il y a une électrode, ou des électrodes (212) disposée(s) de façon que, en service, le milieu qazeux les traverse avant de pénétrer dans le corps (208) de pastilles ou granules (209).

6. Dispositif selon l'une quelconque des revendications 1 à 5, dans lequel il y a des moyens (214, 215, 216) pour ajouter un gaz réactif au milieu gazeux.

7. Dispositif selon l'une quelconque des revendications 1 à 6, convenant bien pour faire partie d'un système ou circuit d'échappement de moteur à combustion interne.

8. Dispositif selon la revendication 7, dans lequel la matière dont les pastilles ou granules (209) sont constitués convient bien pour catalyser la réduction des oxydes NO_x en N_2.

9. Dispositif selon la revendication 7 ou la revendication 8, dans lequel la matière dont les pastilles ou granules (209) sont faits convient bien pour catalyser la conversion de la matière carbonée en des mélanges gazeux de monoxyde de carbone, de dioxyde de carbone et d'eau.

10. Dispositif selon la revendication 8 ou la revendication 9, dans lequel les pastilles ou granules (209)

sont en titanate de baryum.

11. Procédé de réduction des émissions de gaz d'échappement provenant d'un moteur à combustion interne, ce procédé comprenant les étapes consistant à faire passer les gaz d'échappement, provenant d'un moteur à combustion interne, à travers un corps (208) de pastilles ou granulés constitué d'une matière résistant bien à la chaleur et ayant une constante diélectrique élevée, et à appliquer aux pastilles ou granulés (208) un potentiel électrique suffisant pour obliger la matière particulaire contenue dans les gaz d'échappement à se déposer sur les pastilles ou granulés (208).

12. Procédé selon la revendication 11, dans lequel il y a aussi l'opération consistant à ajouter aux gaz d'échappement un gaz réactif convenant bien pour réagir avec les polluants contenus dans les gaz d'échappement.

13. Procédé selon la revendication 12, dans lequel le gaz réactif convient bien pour réduire des oxydes gazeux de l'azote contenus dans les gaz d'échappement.

14. Procédé selon la revendication 13, dans lequel le gaz réactif est l'ammoniac ou l'urée.

15. Procédé selon l'une quelconque des revendications 11 à 14, dans lequel il y a l'opération consistant à soumettre les gaz d'échappement à un champ électrique avant de les faire passer à travers le corps de pastilles ou granulés (209), de façon à charger électriquement la matière particulaire entraînée dans les gaz d'échappement avant leur passage à travers le corps de pastilles ou granulés (209).

16. Procédé selon l'une quelconque des revendications 11 à 15, dans lequel le potentiel électrique est unidirectionnel.

17. Procédé selon la revendication 16, dans lequel le potentiel unidirectionnel est pulsé.

18. Procédé selon l'une quelconque des revendications 11 à 17, dans lequel le potentiel électrique est de l'ordre de 20 kilovolts.

Fig.1.

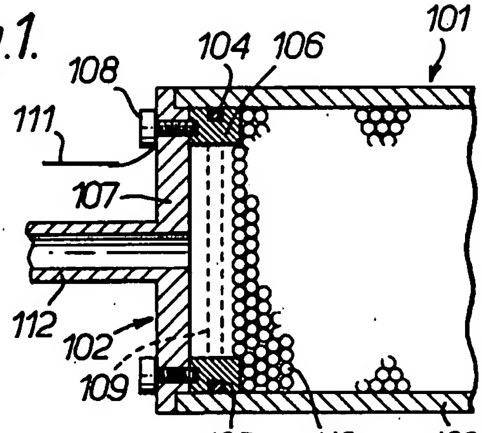


Fig.2.

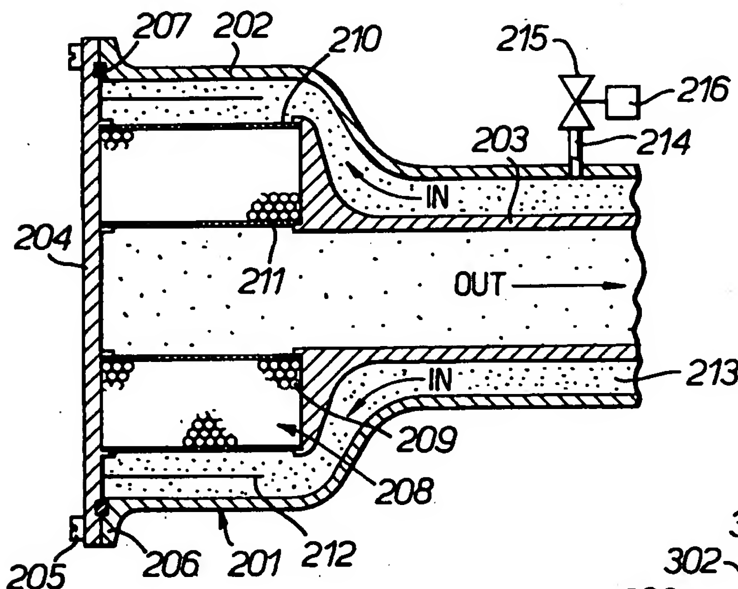


Fig.3.

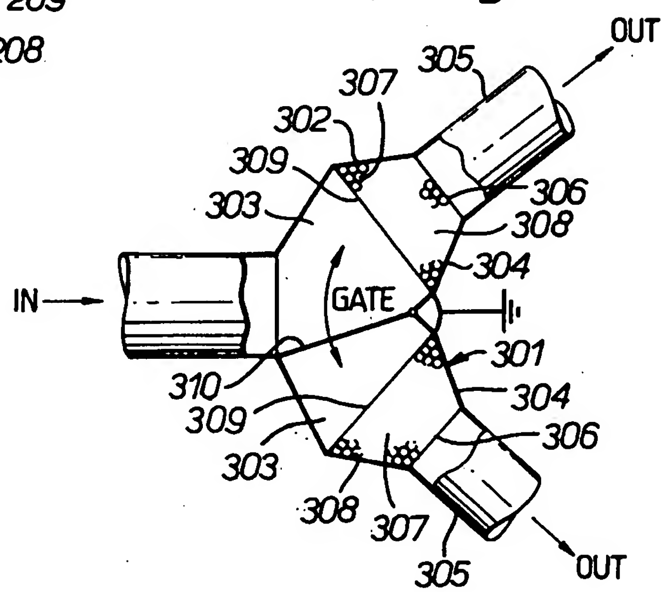
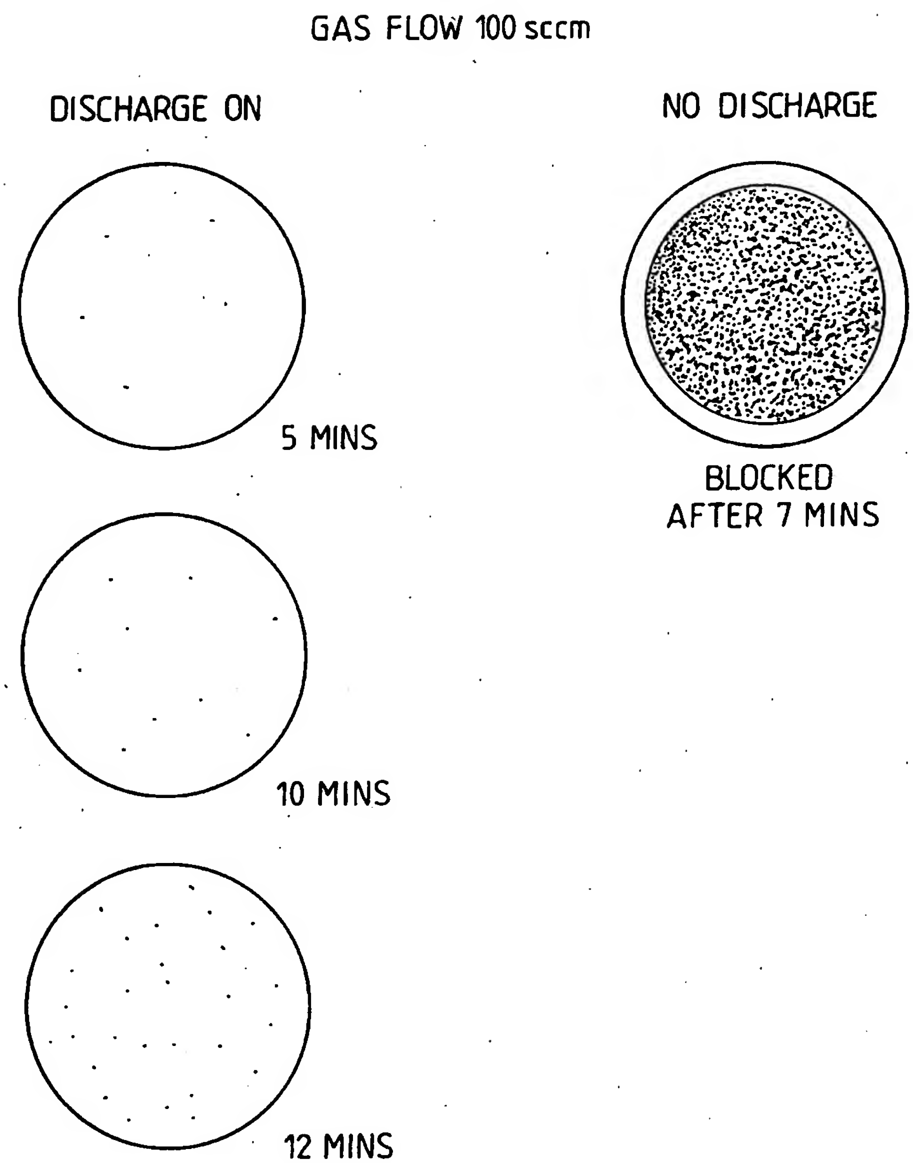


Fig. 4.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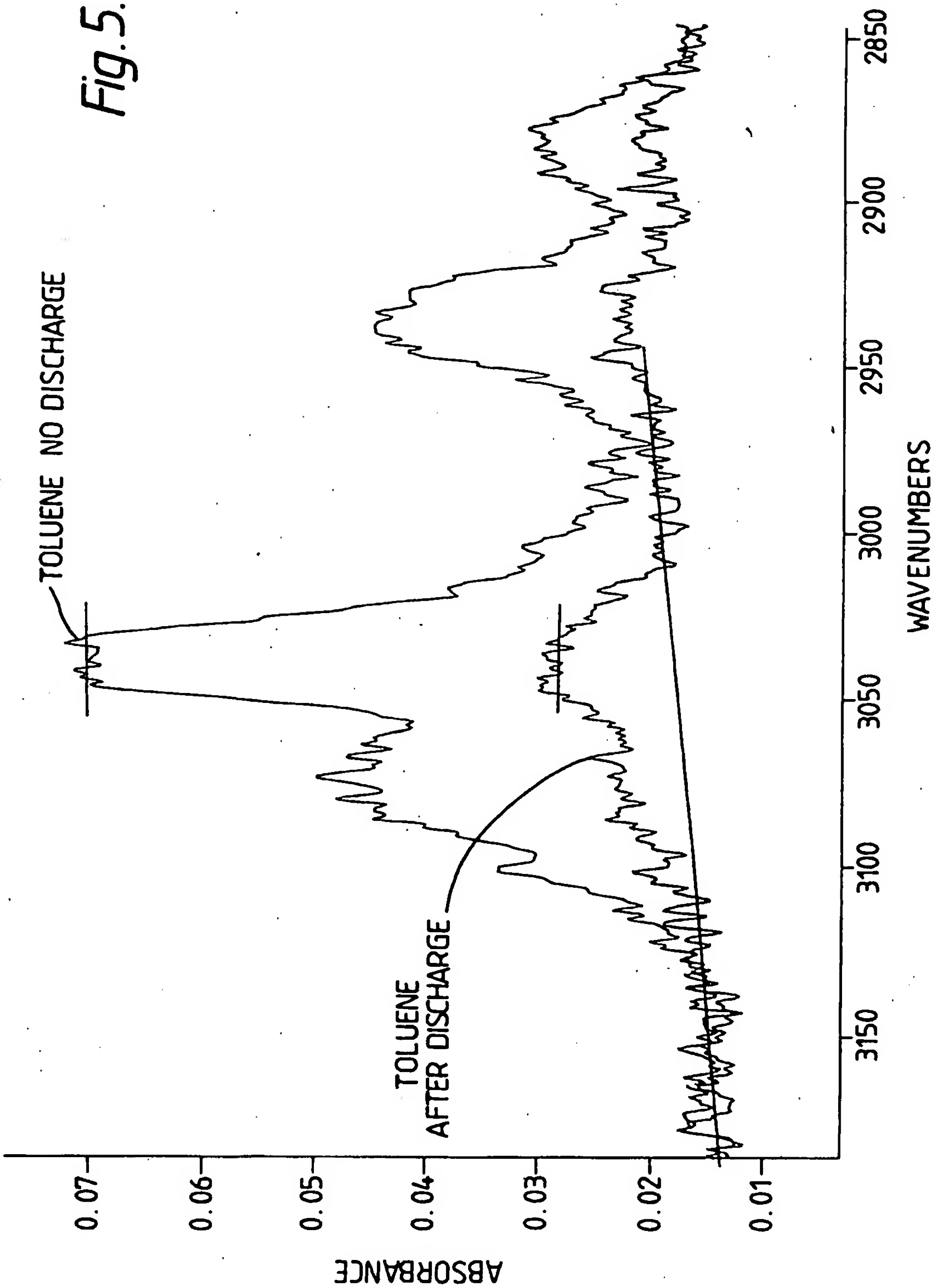
NO DISCHARGE
5 MINS
BLOCKED
AFTER 7 MINS
10 MINS
12 MINS

Fig.5.


TOLUENE NO DISCHARGE
TOLUENE
AFTER DISCHARGE
ABSORBANCE
0.07
0.06
0.05
0.04
0.03
0.02
0.01
WAVENUMBERS
3150
3100
3050
3000
2950
2900
2850